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NRL Memorandum Report 654

PERFORMANCE CHARACTERISTICS OF A TRANSISTORIZED VIDEO AMPLIFIER

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RADIO DIVISION

25X1

6 December 1956

NAVAL RESEARCH LABORATORY
Washington, D.C.

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PERFORMANCE CHARACTERISTICS OF A TRANSISTORIZED VIDEO AMPLIFIER

by

[redacted]

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Countermeasures Branch
Radio Division
Naval Research Laboratory
Washington 25, D. C.

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ABSTRACT

A developmental subminiature video amplifier, employing four surface barrier type transistors was evaluated to determine its performance characteristics under various operating conditions. The inherent small size and weight and low power consumption, combined with the proper electrical characteristics make such transistorized circuits especially interesting in future airborne crystal-video applications, in which simplicity and reliability are of importance. In one series of measurements a direct comparison was made with a conventional crystal-video receiver.

The bandwidth and transient response characteristics were found to be greatly dependent upon the effective input impedance (including the external circuit at the input), and to some extent upon the external load impedance. A 5.5 Mc bandwidth (at the 3 db points) was obtained with a 6-ohm input compared to 0.8 Mc with 10,000 ohms (with a 100-ohm external load). Within the same resistance range, the pulse rise time varied from 0.06 microsecond to 0.35 microsecond.

Voltage gains of 250 (48 db), and 450 (53 db) were measured with and without an external 100-ohm load impedance, respectively. Pulses of either polarity can be applied to the input, but the dynamic range is greater by a factor of two for a positive input pulse.

As a crystal-video receiver, with a 1N23B crystal detector properly biased and connected directly to the amplifier input in the usual manner, the tangential signal sensitivity is comparable to that of a conventional crystal-video receiver with a 1.2 Mc bandwidth. With the same conditions a pulse rise time of 0.4 microsecond is obtained. However, by using a pulse transformer or some other method to couple the crystal-video signal to the amplifier input, a pulse rise time of approximately 0.06 microsecond may be obtained.

PROBLEM STATUS

This is an interim report; work is continuing.

AUTHORIZATION

NRL Problem 54R06-20
BUAER Problem EL 45008
NL 460076

DESCRIPTION OF AMPLIFIER UNIT

The transistorized video amplifier (designed and constructed by [redacted] Corporation), consists of four stages, and uses three L-5108 (SB-100) transistors, and one L-5113 (SB-100 selected for high current amplification factor). The entire circuit, including subminiature components and coaxial input and output connectors is assembled on a printed wiring board approximately 1.25" x 3.5" in size (Fig. 1). The transistors may be seen in the clips. 25X1

The schematic wiring diagram is shown in Fig. 2. The design consists of three common emitter stages followed by an "emitter follower" stage which permits operation into a 100-ohm video cable terminated in its characteristic impedance. In crystal-video applications, crystal bias is supplied through the 10k resistor at the amplifier input. The transistor collector potentials are obtained from a 4.5 volt battery which normally supplies a current of 6 ma, increasing to 8.5 ma when an external load of 100 ohms is used at the output.

For the measurements to be described, it was necessary to install the amplifier unit and batteries in a metal case in order to minimize the effects of stray pickup and interfering signals. Extensive grounding of all the measuring equipment in use was also necessary.

AMPLIFIER PERFORMANCE CHARACTERISTICS

Dynamic Range and Gain

Measurements of dynamic range and gain were made using the method shown in Fig. 3. A 2-microsecond pulse (at a repetition rate of 5000 pps) is obtained from the pulse generator, attenuated to the desired amplitude with the Model #20 Kay Labs. attenuators, and applied to the video amplifier under test through a low-impedance attenuator of 10 ohms (20 db atten.). The amplified output pulse was observed and measured with the oscilloscope (with a high impedance probe) for a complete range of input pulse amplitudes. The data which resulted are shown for positive and negative input pulses, both with or without a 100 ohm external load (Fig. 4).

Several important characteristics can be determined from the curves: (1) With no external load, the amplifier voltage gain is about 450 (53 db) but it is lowered to 250 (48 db) when a 100 ohm external load is connected to the output terminals. (2) Without the external load the maximum output signal available is 1.8 v peak with a positive input (curve A) compared to 1.45 v with negative input (curve C). A 100 ohm external load decreases the maximum output to .75 v with positive input (curve B), and .41 v with negative input (curve D). Thus, it is clear that for best dynamic range, this amplifier circuit prefers a positive input signal. (3) By capacitively coupling the external load (in an effort to prevent changes in the transistor dc operating potentials, and thereby conserve battery power) the maximum output remained the same with a positive input signal (curve B), but was reduced by a factor of 2 when a negative input was used (curve E).

Although a minimum signal input of 100 microvolts is shown on the curves of Fig. 4, signals of much smaller amplitude are discernible. As the minimum detectable signal level is approached, the amplifier input noise becomes more pronounced, making accurate, reproducible measurements increasingly more difficult to obtain, and therefore data at such low levels are not shown. However, the tangential signal sensitivity* was measured with an oscilloscope using video pulses, and found to be about 25 microvolts (peak to peak).

Frequency Response

Several factors were found to influence the transistor amplifier frequency response:

(1) input impedance
(2) load impedance
(3) battery voltage

The effects of these were investigated, using the arrangement shown in Fig. 5a. A variable frequency sine wave oscillator with a 6-ohm output provides a signal with a known amplitude and frequency and the relative output amplitude of the amplified signal is measured with the oscilloscope (10 Mc/s. bandwidth). A high impedance probe (14 micro-micro farads) prevents loading of the amplifier by the oscilloscope input capacitance at the high frequencies.

(1) Effects of Input Impedance: Response curves for conditions of no external load at the amplifier output and 100-ohm termination are shown in Figs. 6 and 7 respectively. For these data, the input resistance (100, 1 k or 10 k ohms) was placed in series between the low impedance generator and the amplifier input. With each value of resistance at the amplifier input, the signal generator output level was adjusted to give a standard amplified output pulse amplitude in the mid-frequency band (10 kc used). In each case the input level was then kept constant throughout the complete frequency range, while the relative output amplitude was observed and measured with the oscilloscope. The curve designated "6 ohms" results when the 6 ohm sine wave generator termination is connected directly to the amplifier.

*Tangential signal sensitivity is defined as the input signal level required to increase the noise deflection by its own height as seen on an A-scope.

In Fig. 6 it can be seen that the 3 db upper cutoff frequency occurs at 4.5 Mc with 100 ohms at the input, but is lowered to 630 kc when the input resistance is increased to 10,000 ohms. Likewise, with an external load on the amplifier output (Fig. 6) the frequency response was reduced from 5.4 Mc with a 100 ohm input resistance to 820 kc with 10,000 ohms.

It is believed that this influence of the input resistance on the frequency response can be attributed to the inherently high effective input capacitance (100 to 300 micro-micro-farads) encountered in a common emitter transistor amplifier, compared to conventional vacuum tube amplifier circuits. As the input resistance is increased the loading effect of the shunt capacitance at the high frequencies becomes increasingly more pronounced.

The low frequency response also depends upon the input resistance, as can be seen in Figs. 6 and 7, deteriorating as the resistance increases. Using a 6-ohm input, the response is peaked at 35 cps with an external 100-ohm load, and at 45 cps with no external load, although the cause of the peak has not been determined. When the input resistance is increased the response peaks tend to flatten.

Measurements were made to compare the performance of the amplifier when the input resistance is connected in shunt instead of series at the input. As was expected, the frequency responses (Figs. 8 and 9) are essentially identical to those obtained with series input resistances (Figs. 6 and 7). For this set of data the circuit of Fig. 5b was used. At each value of input resistance, R_i, the series isolation resistance, R_s, was chosen to be high in value compared to R_i, so that looking back to the generator the amplifier sees a shunt resistance which is effectively R_i. The generator output was insufficient when a 10 k input resistance was used, and therefore such data could not be taken.

(2) Effects of Load Resistance: Some degree of improvement in bandwidth is obtained by using an external 100-ohm load resistance at the amplifier output. A comparison of Figs. 8 and 9 shows, for example that with a 1000-ohm input resistance, using the external load the 3-db bandwidth increases from 1.4 Mc to 2 Mc. With other values of input resistance similar bandpass improvement results.

(3) Effects of Battery Voltage: Input capacitance and resistance of a transistor vary with collector current (Fig. 10), and therefore it can be expected that the high frequency response may also vary. Comparative measurements were taken using the normal 4.5 v. supply and 3 v. with input resistances of 100 and 1000 ohms, and with and without the external load. The response curves (Fig. 11), illustrate that as the battery voltage is lowered, the bandwidth diminishes. At the low frequencies no effects of supply voltage change were noted, and therefore these data are not shown.

Transient Response

Transient response measurements were made using the method given in the block diagram of Fig. 12. A pulse with a fast rise time (.02 microsecond), and a 2 μsec duration (at 100 pps) is produced by the pulse generator, sufficiently attenuated, and applied to the amplifier under test. The resistance divider (47 ohms and 5 ohms) provides an impedance match for the 50-ohm variable attenuator, and also a low impedance at the amplifier input. This input impedance is then increased by the addition of various values of resistances (R_i) to simulate a range of amplifier input resistances. Pulse rise time measurements were made throughout a range of input resistances from 5 to 50,000 ohms, using a wide-band (10 Mc/Sec.) Tektronix oscilloscope (Model #531).

Fig. 13 gives the measured pulse rise time (10 to 90 percent) in microseconds as a function of input resistance, both with and without an external 100-ohm load resistor. It can be seen that at first the rise time increases slowly with increasing input resistance, but from 100 ohms to 10,000 ohms the increase is rapid and at higher values the change is again slow. Also, an improvement in pulse response is evident when the external load is connected (see curve A of Fig. 13).

Fairly good correlation exists between these data and the frequency response data previously shown. For example, considering the 1000-ohm external load condition and 1000-ohm input resistance a rise time of .2 microsecond is obtained (Fig. 13). Calculating from the equation: $\Upsilon \mathcal{B} = .35$, in which Υ = pulse rise time and $\mathcal{B}$ is the 3 db bandwidth of the amplifier, $\mathcal{B}$ is 1.75 Mc. Referring to the related frequency response curve (See Fig. 7) the 3 db cutoff frequency is 1.8 Mc. (A 1000-ohm input resistance was selected for the example since this is the approximate video resistance of a silicon detector crystal with optimum bias. This will be shown subsequently.)

Pulse Overload

No appreciable overshoot, sag, or other forms of pulse distortion are evident at low signal levels. But as the signal amplitude is increased, overloading the amplifier, pulse distortion occurs. Observations were made at various overload levels, and the results were tabulated in Table 1. A 1-microsecond pulse was applied to the amplifier through a 50-ohm attenuator, and its amplitude was increased to the limiting overload level. From this point (the overload level) the amplitude was further increased in 10-db steps and the various effects on the output pulse shape recorded. A 100-ohm external load was used for this series of measurements.

TABLE 1 - Effects of Pulse Overload

Overload (db)	Pulse Duration (microseconds)	Overshoot	Other Effects
0	1	None	
10	1.2	None	
20	1.5	None	
30	1.8	None	
40	2.0	less than 5%	ringing on trailing edge
50	2.0	5%	serious ringing

CHARACTERISTICS WHEN EMPLOYED AS A CRYSTAL-VIDEO RECEIVER

In crystal-video receivers an amplitude-modulated r-f signal from an antenna is detected by a crystal diode, the resulting video signal is amplified, and displayed or analyzed. The receiver is wide-open in frequency and responds instantaneously to signals within the frequency range of the associated antenna system. The amplifier, in conjunction with the crystal detector, must be capable of providing the necessary sensitivity to detect low level signals, and also good fidelity, so that the video pulse characteristics can be determined.

By applying the proper forward bias to the crystal detector, each of these characteristics can be optimized. These improvements occur because crystal bias lowers the crystal video impedance permitting a better match with the input circuit, and also minimizing the effect of capacitive loading by the input and video cable capacitance. Fig. 14 shows video impedance as a function of crystal bias current for a typical 1N23B detector.

The performance of the transistorized amplifier was compared with that of a typical 1.2 Mc crystal-video receiver, the R-467(XB-2)/ALR (See ref. a.), which consists of conventional vacuum tube circuits. The test set-up is shown in Fig. 15. A microwave signal generator provides a 4 kMc pulse-modulated signal (with pulse duration of 2 microseconds, and repetition frequency of 4000 pps) which is detected by a crystal diode, amplified and viewed on a wideband oscilloscope. Crystal bias, variable from 0 to 400 microamps. is supplied by an external bias supply. The crystal mount (Polytechnic Research and Development Co., Mod. 613) was connected directly to the R-467 receiver, or the transistorized amplifier under test, thus eliminating the usual length of video cable and its capacitive loading effects. These effects of capacitive loading were determined later, in a separate series of measurements.

Tangential Signal Sensitivity

Tangential signal sensitivity was measured using a typical 1N23B crystal connected to either the amplifier or the R-467 receiver and with bias currents ranging from 0 to 300 microamps. The resulting data are shown in Fig. 16. There was no difference in tangential sensitivity between the conditions of no external load and 100-ohm load, and therefore only one curve is shown to represent both conditions.

The sensitivity curves of the two systems differ in several respects. First, it is noticed that the maximum sensitivity available with the amplifier is slightly lower (2 db) than that of the receiver. Second, the crystal bias current for optimum sensitivity varies between the two units: about 20 microamps. for the receiver, and 20 - 50 microamps. with the amplifier (it will be shown that 50 microamps. should be used). Third, in the low current region (less than 10 microamps.) the sensitivity of the transistorized amplifier is subject to greater changes with variations of bias. From no bias to optimum bias, a 9-db improvement (-45 dbm to - 54 dbm) in sensitivity takes place with the transistorized amplifier, compared to 6 db (-50 dbm to -56 dbm) with the R-467 receiver. This indicates a greater requirement for bias by the transistorized amplifier.

Pulse Response with Crystal Input

As the crystal detector bias is increased, lowering the video impedance, the capacitive loading of the amplifier (or receiver) input circuit becomes less effective and, therefore, the amplifier pulse fidelity is improved. This is exemplified by Fig. 17, in which pulse rise time is plotted as a function of crystal bias current for the amplifier and also the receiver. A comparison of these curves shows that at low values of bias current, changes in current have less effect on pulse rise time when using the transistorized amplifier than when using the video receiver. This is expected, because in this bias region the crystal-video impedance becomes quite high (more than 5000 ohms), and has less shunting effect on the transistorized amplifier which has a relatively low input impedance, than on the receiver. As the bias is increased, the pulse rise time of the transistorized amplifier continues to improve*, while that of the receiver remains constant. In this case the effective input impedance of the transistorized amplifier depends upon the crystal impedance which decreases to a low value camparable to the amplifier input impedance. An increase of response is not indicated by the receiver unit because the overall pulse response is limited (to .4 microsecond) by the stages following the input circuit. With the receiver unit, optimum rise

*Since the signal generator produces a modulating pulse with a rise time of approximately .25 microsecond, the amplifier output pulse rise time is limited to this value. Therefore, at high levels of bias (200 - 300 microamps.), the rise time of the amplifier alone is actually faster than is shown in Fig. 17.

time is obtained at 30 microamps. (Fig. 17), which is within the current range required for best sensitivity (Fig. 16). But with the amplifier, for optimum rise time the crystal bias must be about 300 microamps. Operating the crystal at this point gives an 8-db loss in sensitivity compared to optimum which is 20 - 50 microamps. (Fig. 16). By selecting the bias (50 microamps. for the amplifier and 30 microamps. for the receiver) so that optimum sensitivity is obtained in either unit, the pulse rise time is about the same (.4 microsecond) in both, despite the more adequate bandwidth of the transistorized amplifier, compared to that of the R-467(XB-2)/ALR receiver. The significance of these comparisons is that although the transistorized amplifier is basically a wide-band amplifier, its response capabilities are limited by its input circuit when a crystal (biased to give optimum sensitivity) is employed at the input.

It should be pointed out that the above comparative response characteristics apply only when a crystal detector is connected directly to the amplifier input in the conventional manner. Alternative methods of coupling the video signal from the crystal to the amplifier, such as with a pulse transformer, may be used to minimize the input loading effect, thereby resulting in an improved pulse response. In this way, a rise time as short as 0.06 microsecond is possible.

Effects of Video Cable Capacitance on Pulse Response

The r-f measurements which have been discussed, were made with the crystal detector and mount connected directly to the amplifier, or receiver input. But in practice a crystal mount is generally connected to an antenna element, and a video coaxial cable is required to feed the detected output of the crystal to the amplifier, which may be remotely located. The distributed capacitance of a cable, such as RG-71/U (13.5 micro-micro-farads per foot), added to the amplifier input capacitance affects the overall amplifier response, and therefore the pulse shape.

With various lengths of cable (RG-71/U) connected between the crystal detector and the transistorized amplifier, data were taken at various levels of crystal bias current. The frequency of the generator was set at 4 kMc and internally modulated with pulses of 3 microseconds duration and 4000 pps. The r-f input level to the amplifier was adjusted to give an amplified output pulse about 6 db down from the saturation level, to eliminate pulse distortion. The data are shown graphically in the family of curves of Fig. 18. Referring to these curves, the greatest effects on pulse rise time are noticed at the lower bias values, where the crystal video impedance is the highest, and thus, the capacitive shunting is most pronounced. When applying 35 to 50 microamps. (the region of optimum sensitivity) through the crystal it is seen that only 3 feet of video cable will cause degradation of the pulse response. As the bias is increased, the crystal impedance is lowered sufficiently to permit the use of longer lengths of cable without seriously affecting the pulse rise time (10 ft of cable at 300 microamps.). Again, it should be pointed out that at 300 microamps. with small cable lengths the rise time approaches the generated pulse rise time, and therefore the amplifier rise time is actually less than indicated.

It was found that at the amplifier output, when a video cable was terminated by a 100-ohm resistance, cable length was not critical. Up to 85 feet of RG-71/U was used, and the rise time increased only slightly at any bias level. These data indicate that the amplifier should be located as close as possible to the crystal detector and its associated antenna. Operating with 50 microamps. of bias, the input video cable (RG-71/U) must be less than 5 feet long, while as much as 85 feet of cable can be tolerated at the output.

R-F Input Level Required to Produce Overload

Fig. 20 gives the maximum r-f signal input which can be applied to a 1N23B crystal at the amplifier input, before the point of overloading is reached, producing pulse distortion. At the bias level of optimum sensitivity, the detected video signal is maximum, and therefore at this point a lower level of r-f input is required for amplifier overload, as shown in Fig. 20.

When the overload level is exceeded, pulse overshoot occurs, during which time the amplifier is less sensitive to other signals. It is important that the recovery time from this "blocking" effect be as short as possible so that the amplifier performs with normal amplification as soon as possible. The transistorized amplifier (with a crystal input) was subjected to various degrees of r-f overloading up to 30 db above saturation level, and the measured recovery time appeared to be 250 microseconds within the complete range. Pulse durations of 1 and 10 microseconds were used, with identical results.

Noise Level

With no crystal at the amplifier input the output noise level is about 3.6 mv.(rms) with no external load and 2.3 mv. using a 100-ohm load. Using the gain figures previously obtained, the noise input is about 9 microvolts. By the addition of a 1N23B crystal with forward bias of 50 microamps. at the input, essentially no change in noise takes place.

Gain Control

A gain control circuit, suggested by the designer of the amplifier, was incorporated into the unit to determine its feasibility. It was intended for use with a crystal detector input, in which variations in crystal bias produce changes in sensitivity. The circuit consists of an additional battery and a potentiometer (Fig. 21) which, in conjunction with the collector battery, provides a wide range of potentials from negative to positive. The bias is applied to the crystal through the 10 k resistor at the input.

Although some degree of gain control was obtained, this method of control was determined to be unacceptable for several reasons. First, since the 20-μf input capacitor is polarized (with its positive terminal at the crystal), any reversal of battery potential from positive to negative causes conduction of current through this capacitor as well as through the crystal. However, this can be overcome by using a non-polarized capacitor. Second, by reversing the crystal bias from forward (positive) to backward (negative), operation of the crystal became very unstable. Rapid and random changes in detection polarity occurred, depending upon the combination of reverse bias level and r-f power level. Third, varying the crystal bias also produces changes in overall amplifier response, thus affecting the pulse shape. This has been discussed previously.

Crystal Bias Considerations

The polarity of the crystal bias, supplied through the 10 K resistor at the amplifier input, is determined by the type of crystal detector used, and the manner in which it is connected to the amplifier input. Silicon crystals of normal polarity (such as the 1N23B), installed in a crystal mount (such as the PRD-613) which permits the detected video signal to be taken from the silicon end (base), require a positive bias. The detected video pulse in this case is negative. When positive video pulses are required, crystals of reversed polarity (1N23BR) can be used with the same crystal mount, provided that the bias polarity is reversed (negative). The latter mode of operation may be desirable, since it has been shown in Fig. 4 that the amplifier dynamic range is greater with positive video input.

It has been pointed out that in its present form, due to the 20-microfarad polarized electrolytic coupling capacitor at the input, the amplifier can accommodate only positive bias. Reversing this capacitor or replacing it with a non-polarized one will permit the use of negative bias.

CONCLUSIONS

1. The overall frequency and transient response characteristics depend greatly upon the circuit connected to the input terminals, and to some extent upon load impedance, inter-connecting video cable capacitance, and the battery voltage.

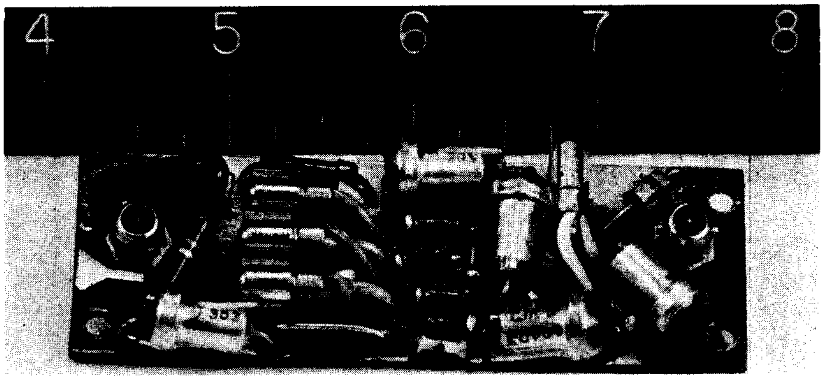
2. Input pulses of either polarity can be amplified, but the dynamic range is greater with a positive input.

3. As a crystal-video receiver, employing a 1N23B crystal detector (properly biased) connected directly to the amplifier input, the tangential signal sensitivity and the pulse response characteristics are comparable to those of a conventional crystal-video receiver (R-467(XB-2)/ALR), with a 1.2 Mc bandwidth. By using a pulse transformer or some other method to couple the detected video signal from the crystal to the amplifier, the pulse response may be improved considerably.

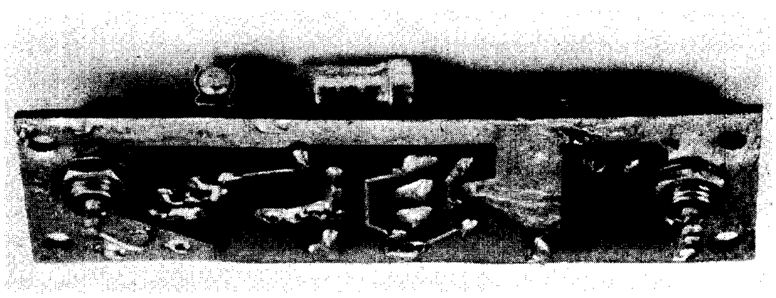
4. The polarity of the 20-microfarad input coupling capacitor is such that only crystals requiring positive bias can be accommodated. When negative bias is required, such as by a reversed polarity crystal, the capacitor should either be connected in reverse, or replaced with a non-polarized capacitor.

REFERENCES

(a) "Handbook of Maintenance Instructions [redacted] R-467(XB-2)/ALR and Antennas AT-406(XB-1)/ALR and AT-407(XB-1)/ALR" (Confidential) by Naval Research Laboratory, November 1, 1952. 25X1



a. Components side



b. Printed circuit side

Figure 1 - Video amplifier unit

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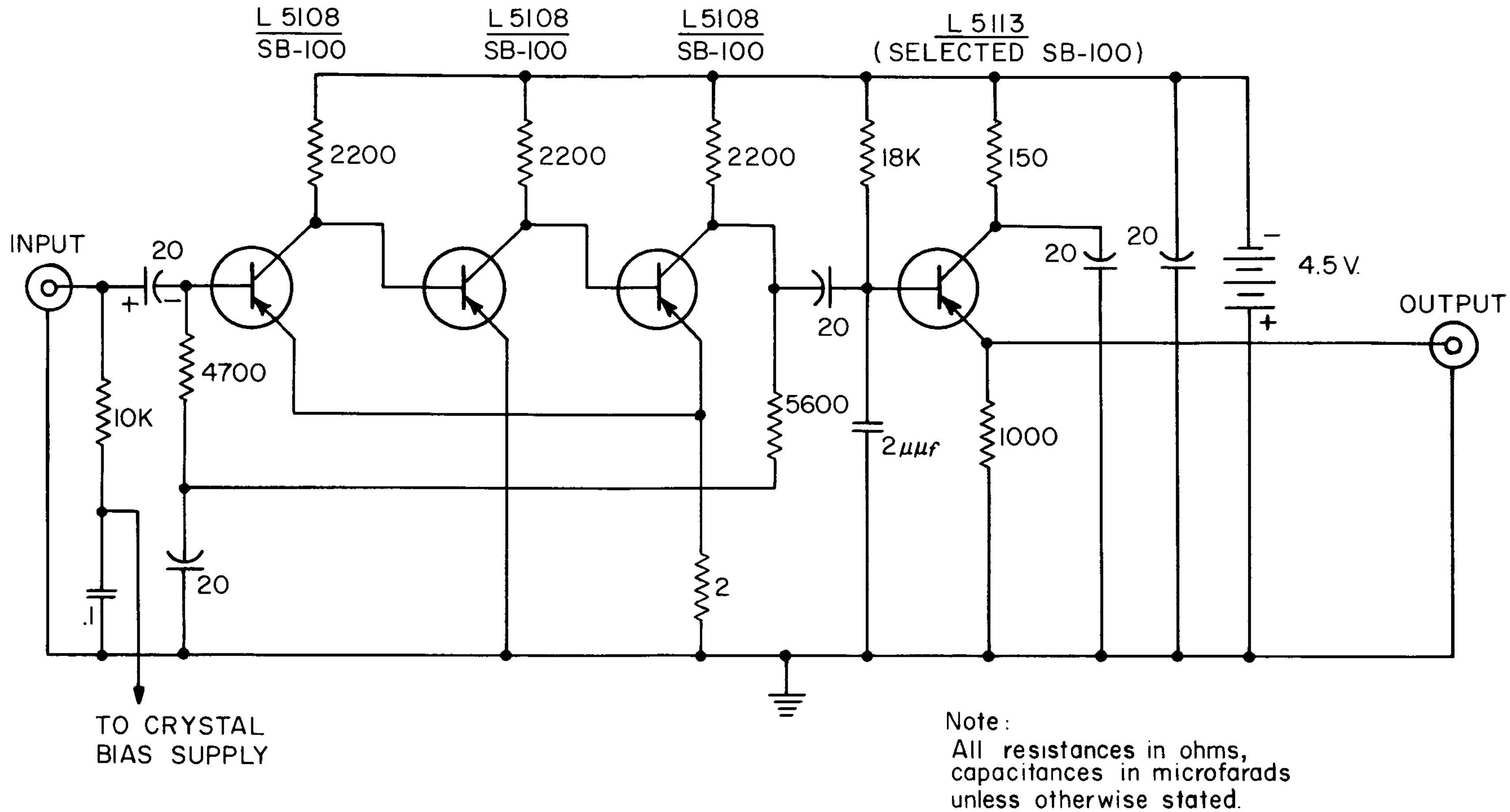


Figure 2 - Schematic wiring diagram

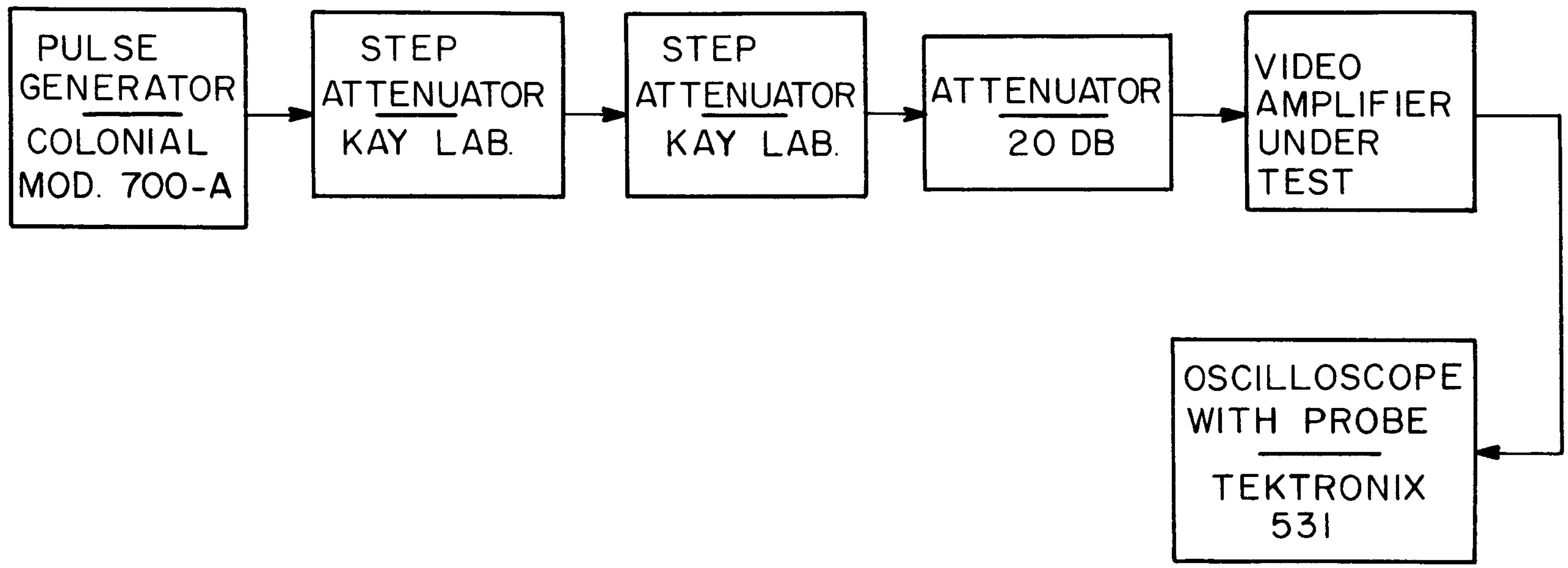


Figure 3 - Block diagram of arrangement for gain and dynamic range measurements

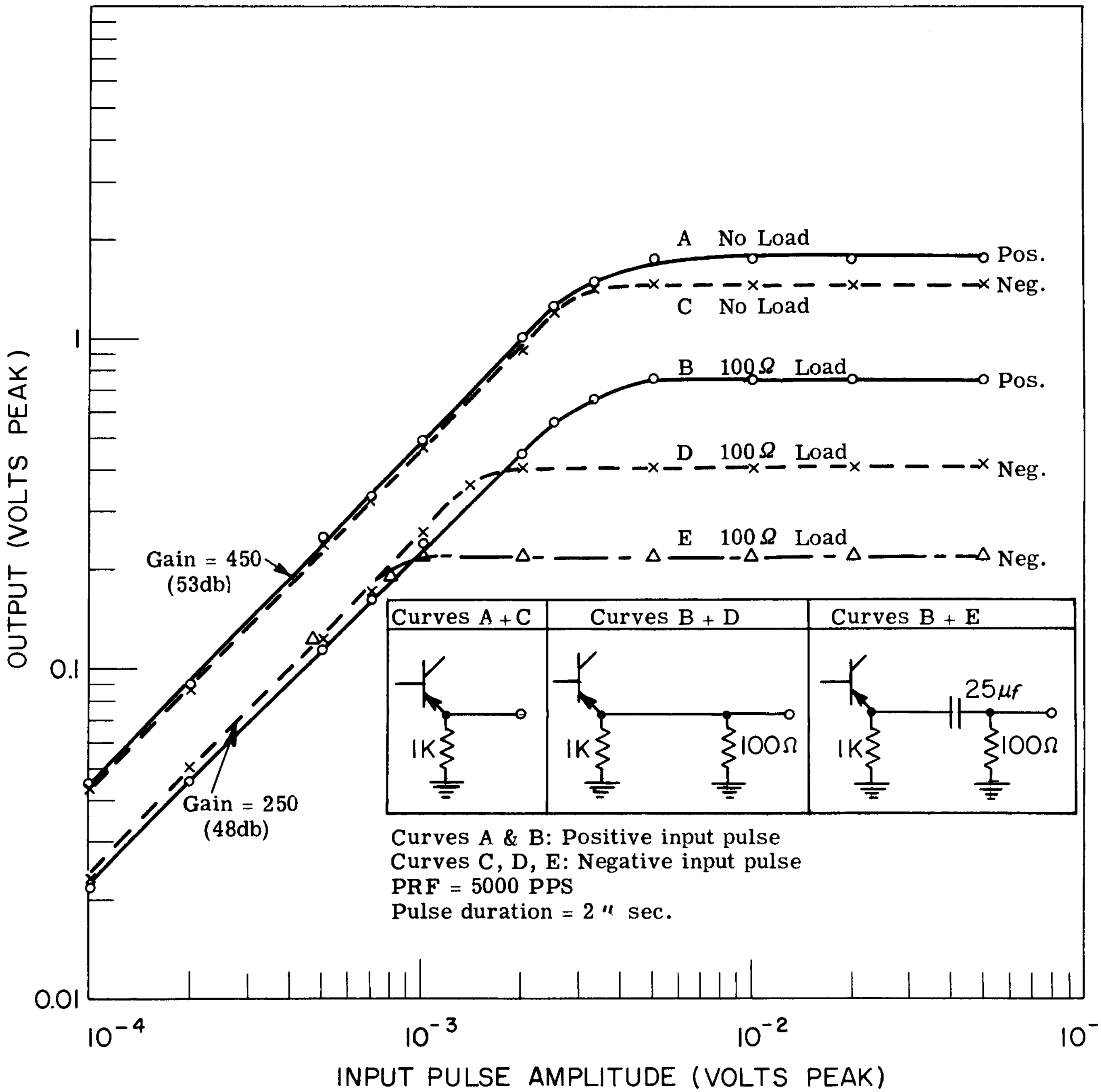


Figure 4 - Output versus input

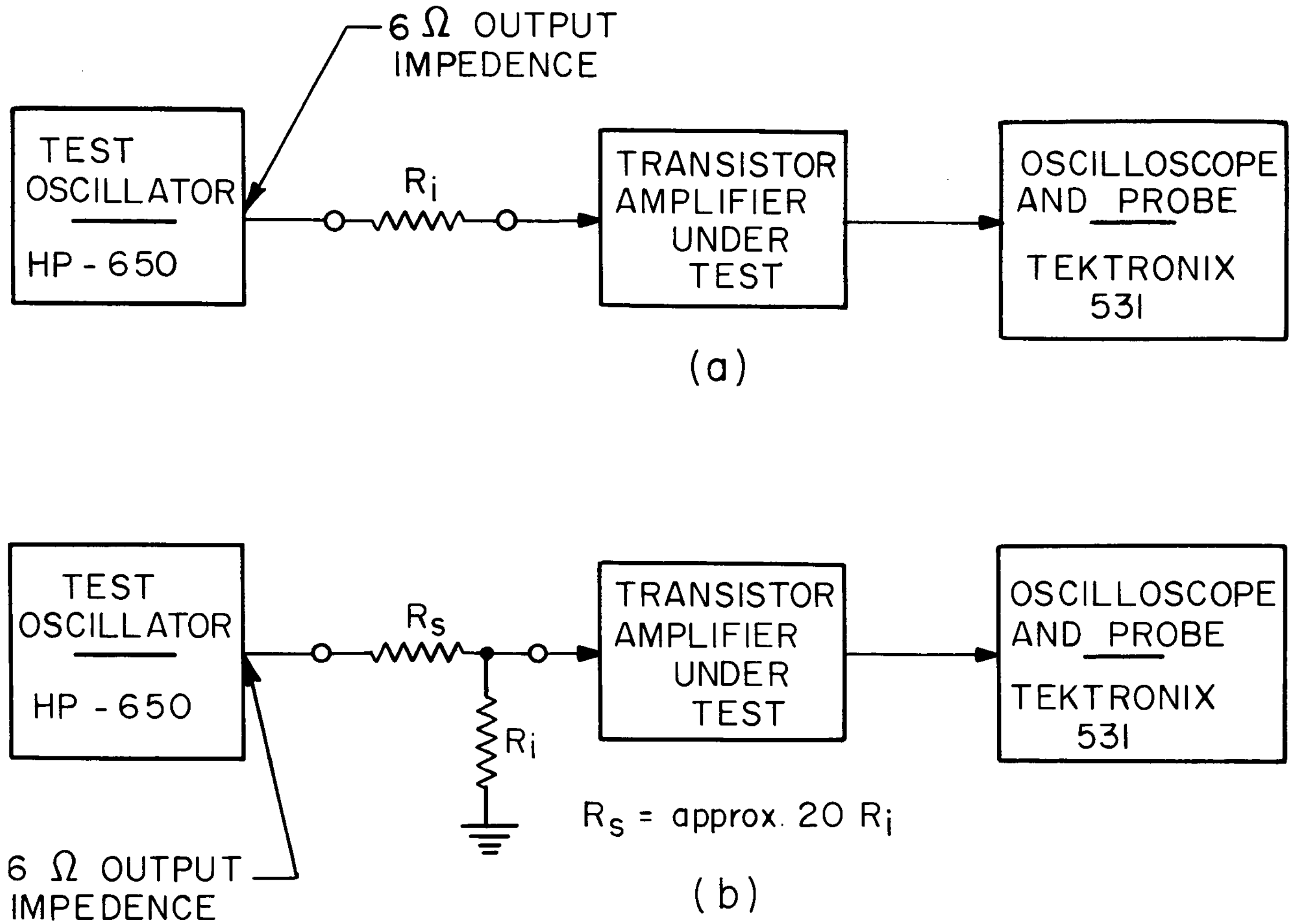


Figure 5 - Block diagram of equipment used for frequency response measurements. (a) Input resistance in series with amplifier input. (b) Input resistance in shunt at the input

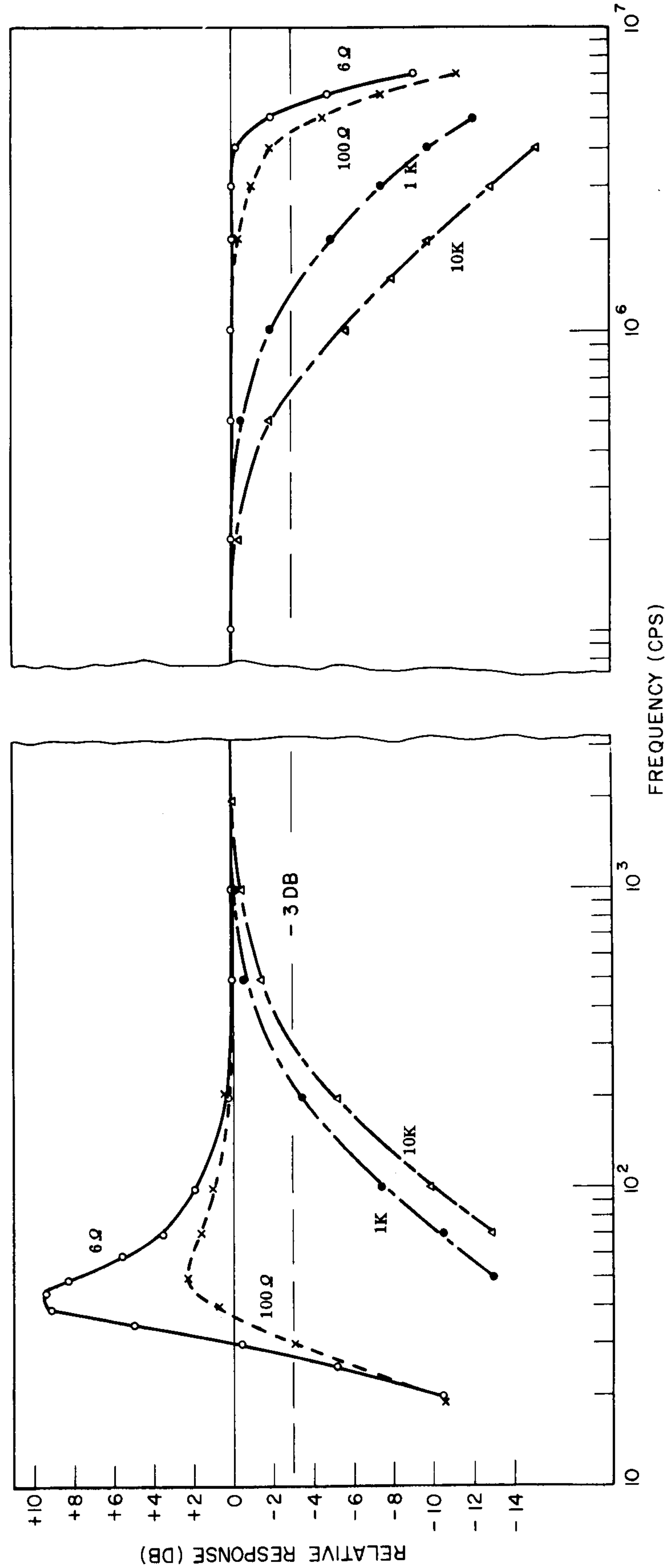


Figure 6 - Frequency response with various values of series input resistance and no external load resistance

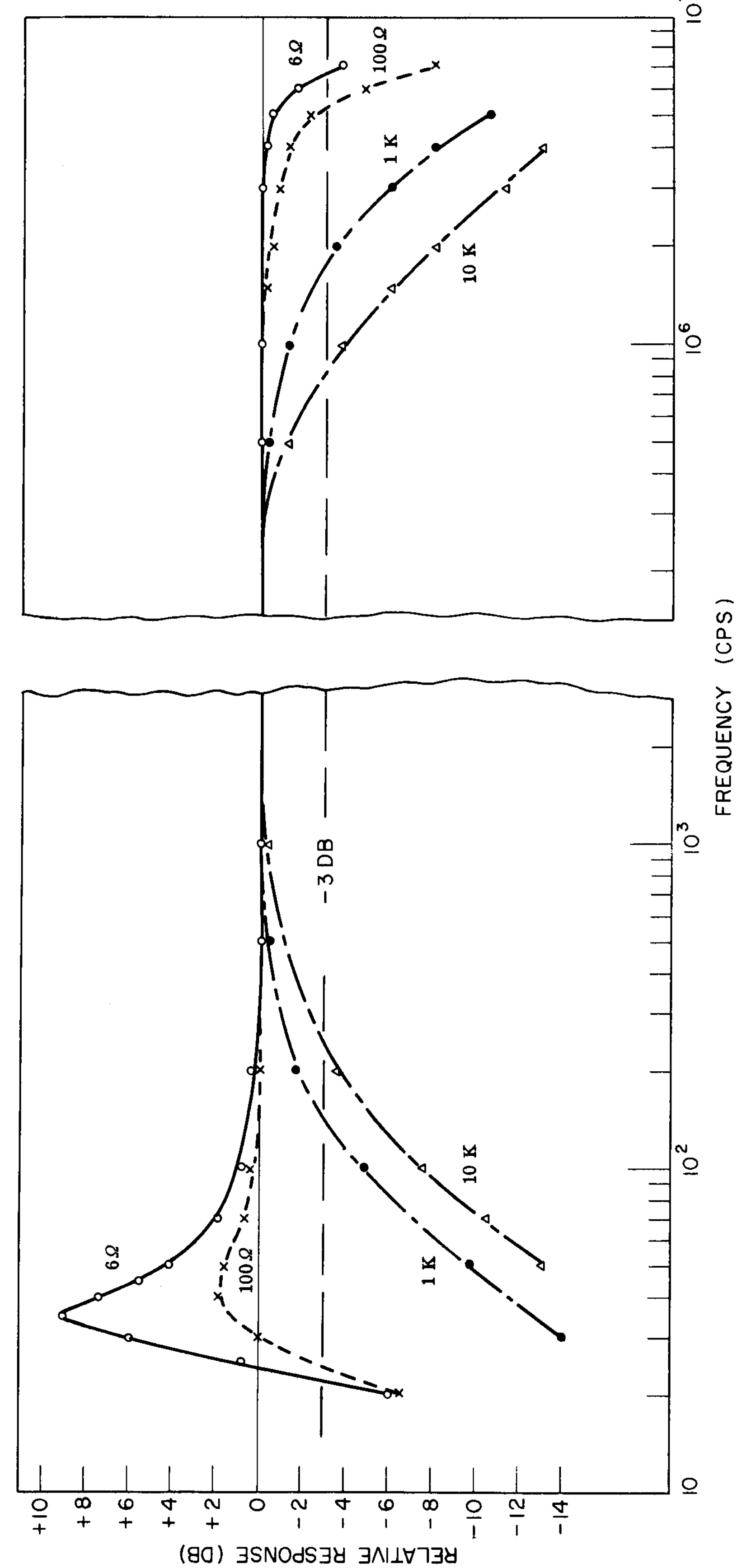


Figure 7 - Frequency response with various values of series input resistance and 100-ohm load resistance

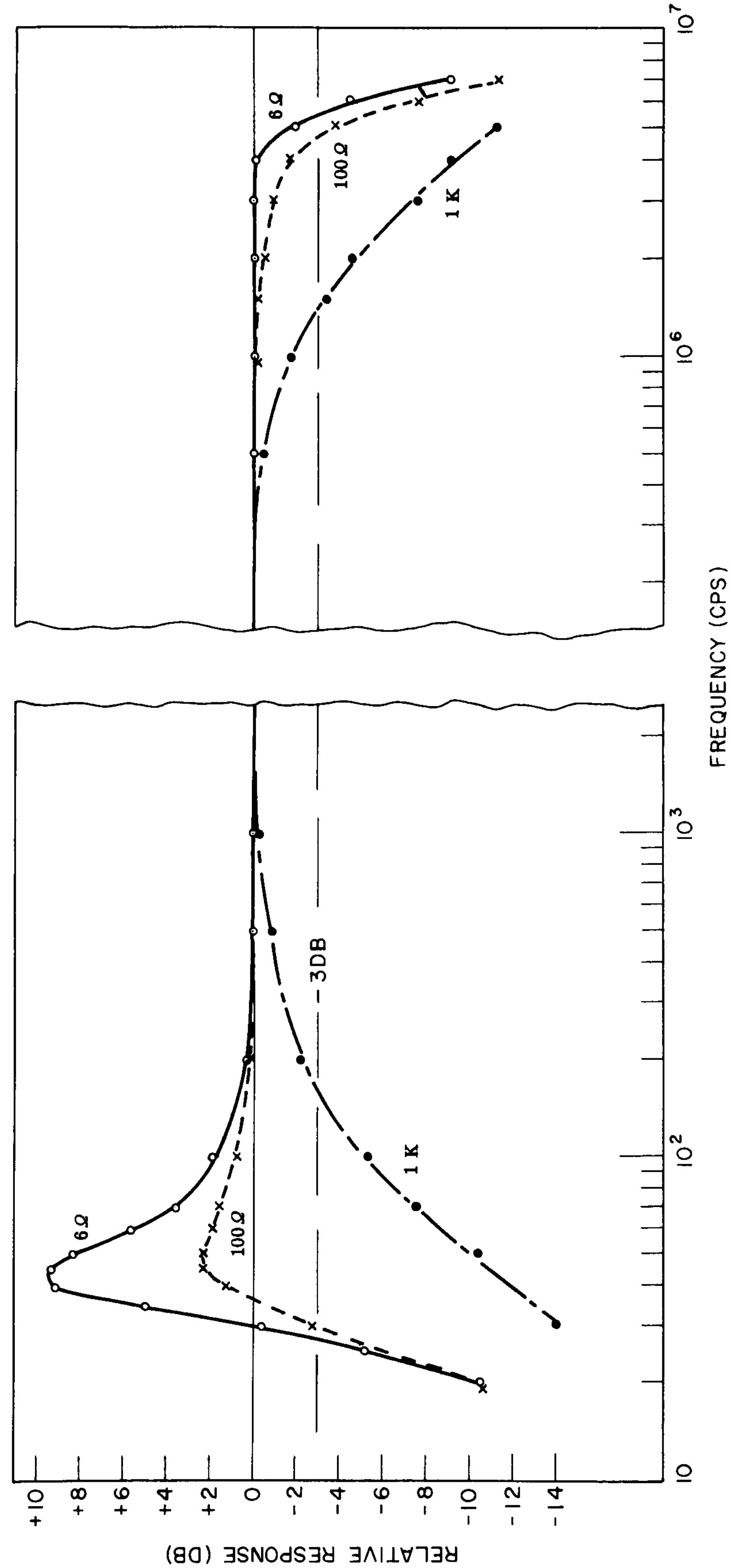


Figure 8 - Frequency response with various values of shunt input resistance and no external load resistance

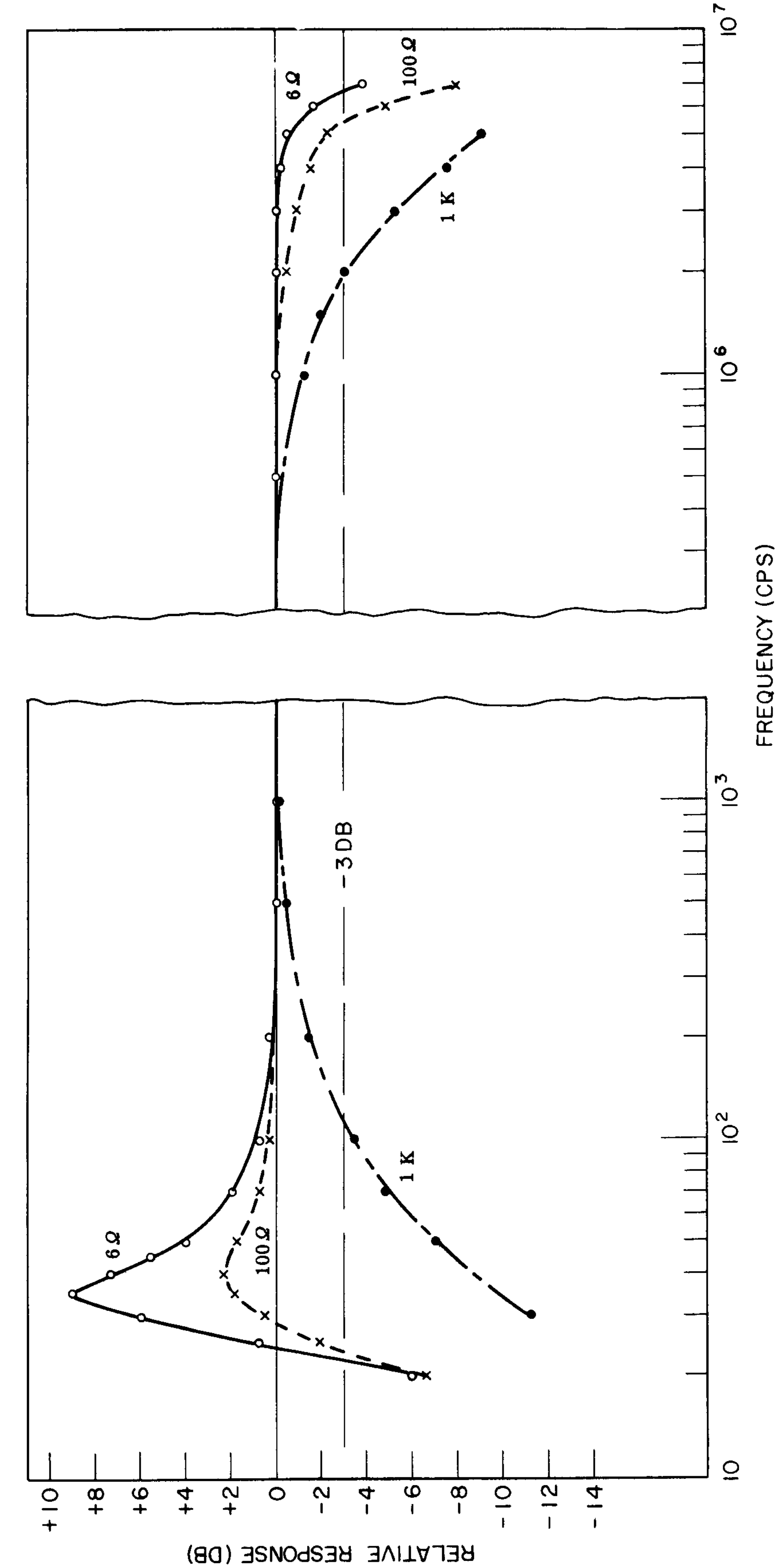
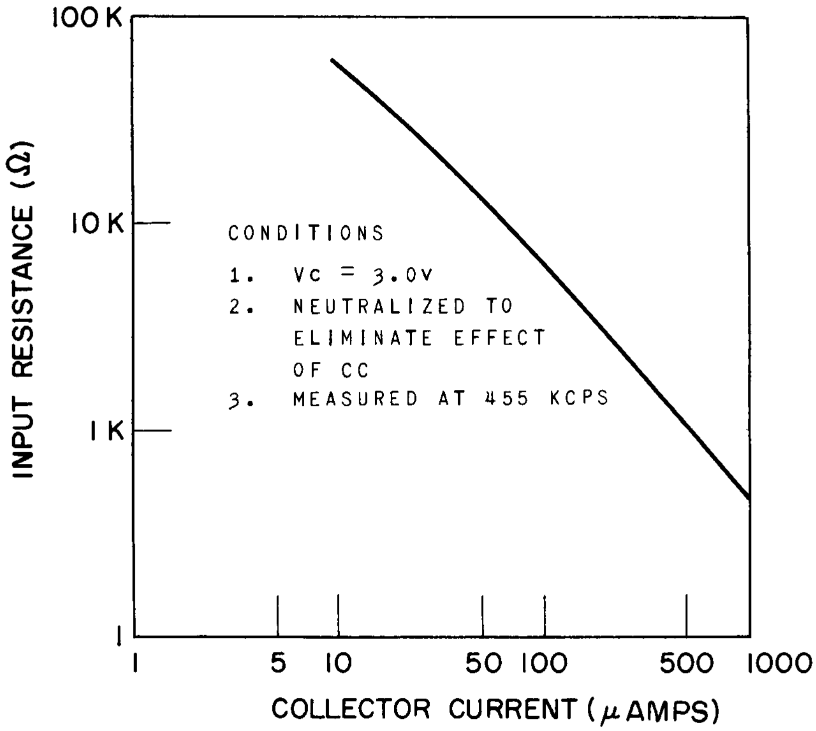
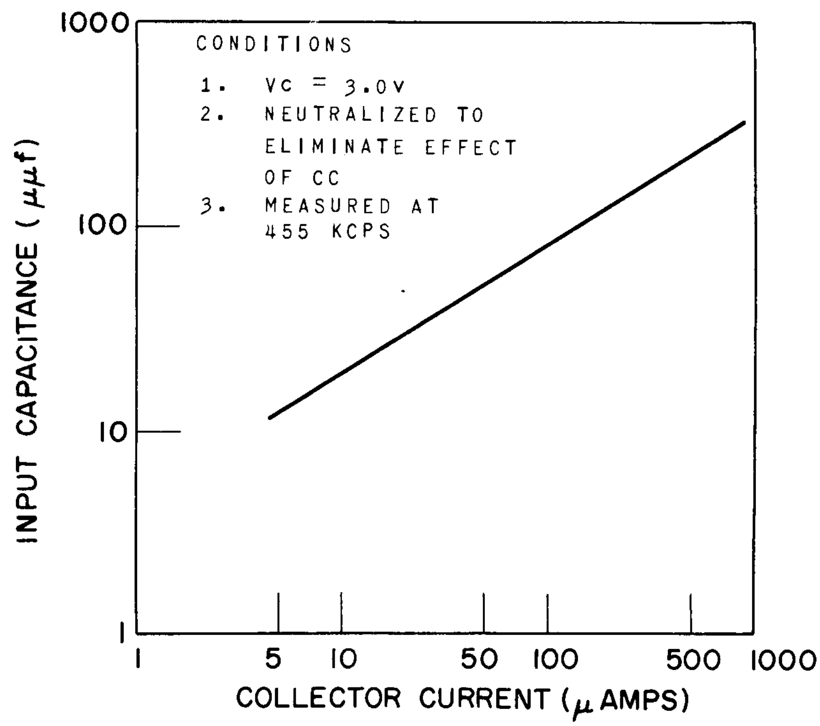


Figure 9 - Frequency response with various values of shunt input resistance and 100-ohm load resistance



(a)



(b)

Figure 10 - Common emitter input resistance. (a), and input capacitance (b) versus collector current. (Taken from [redacted] data sheet.) 25X1

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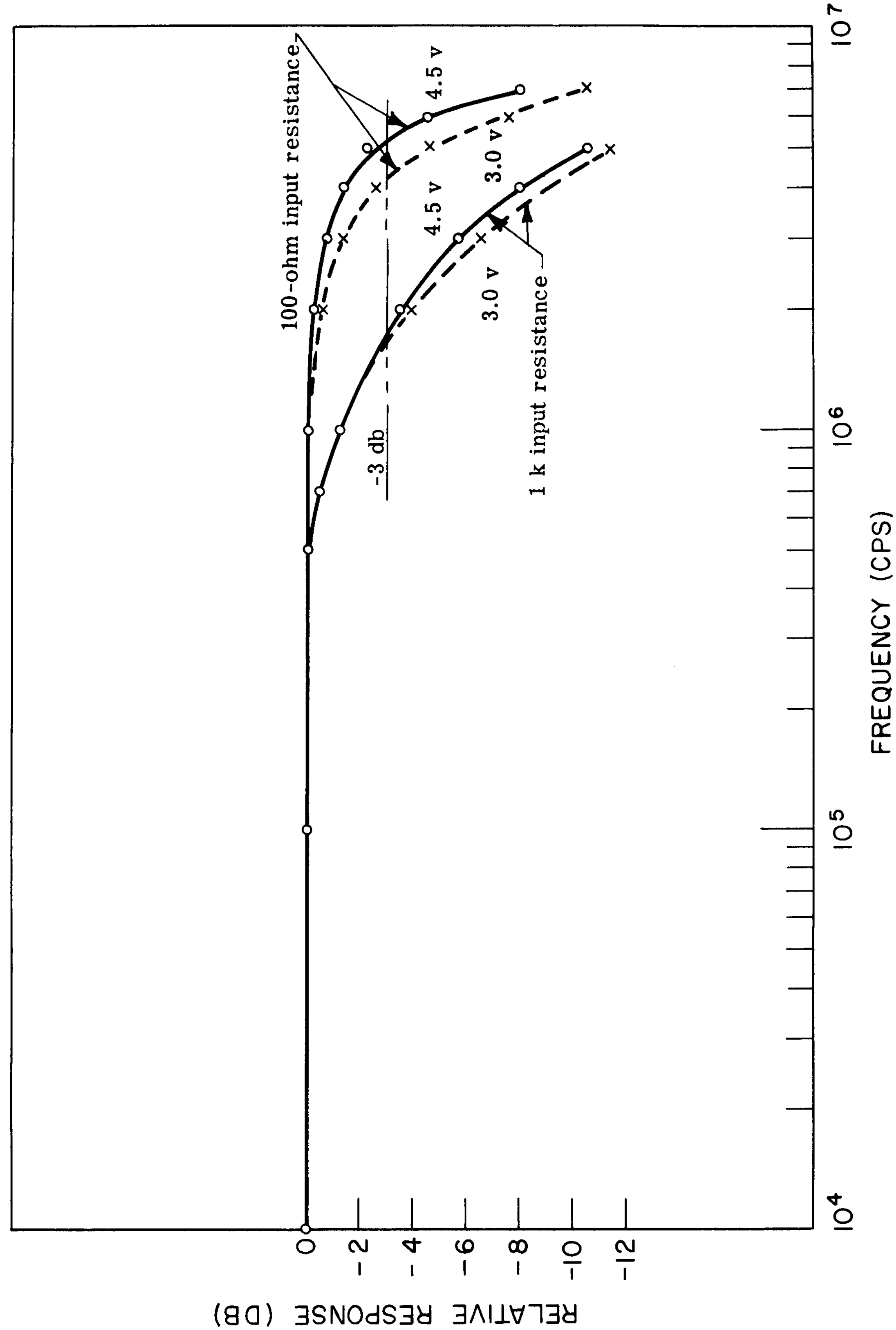

Figure 11 - Frequency response using 3-volt and 4.5-volt battery.
(100-ohm load)

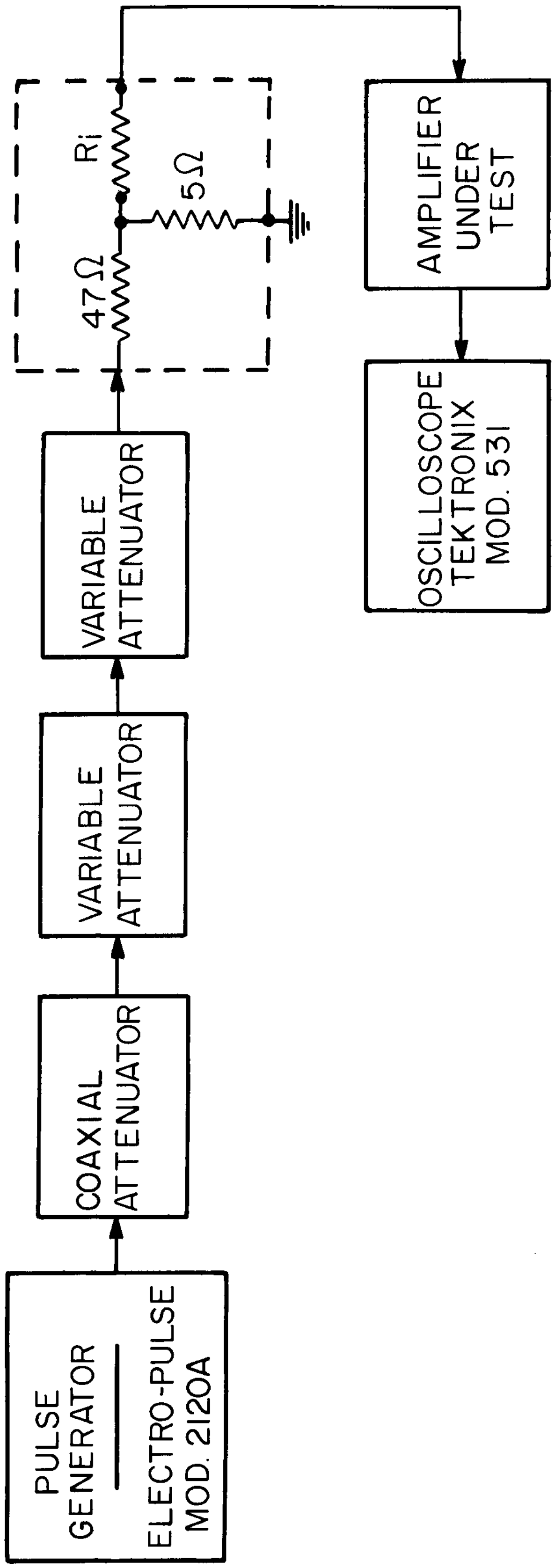

Figure 12 - Block diagram of equipment for transient response measurements.

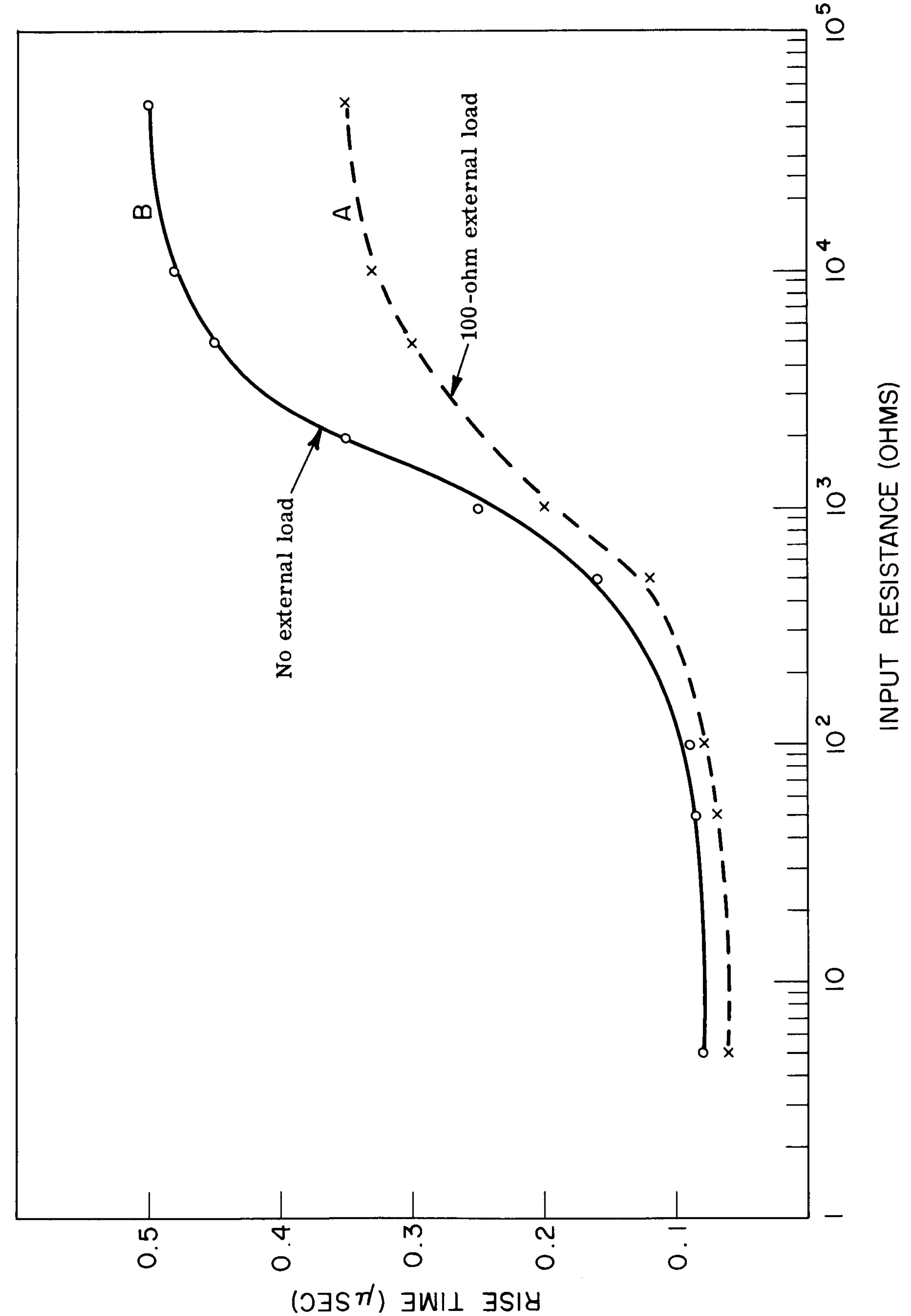

Figure 13 - Pulse rise time versus input resistance

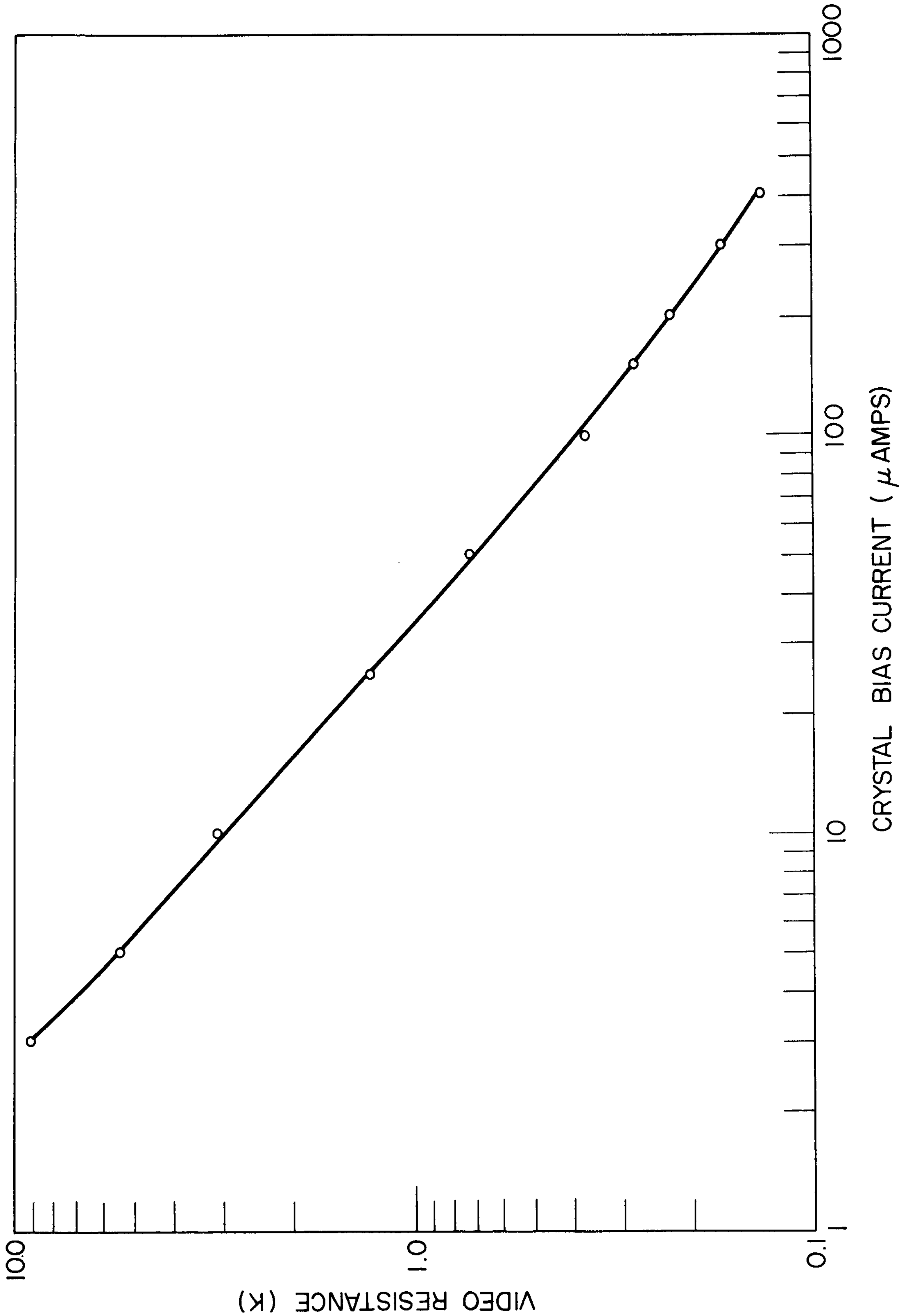

Figure 14 - Crystal video resistance versus bias current for typical IN23B

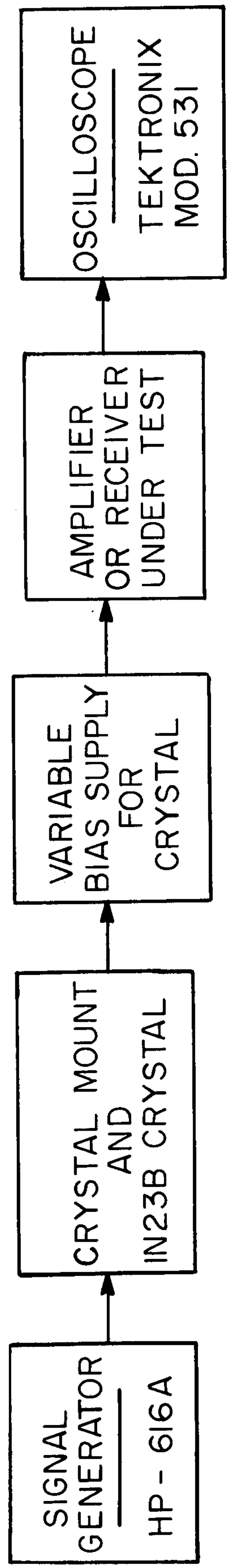

Figure 15 - Block diagram for r-f measurements equipment

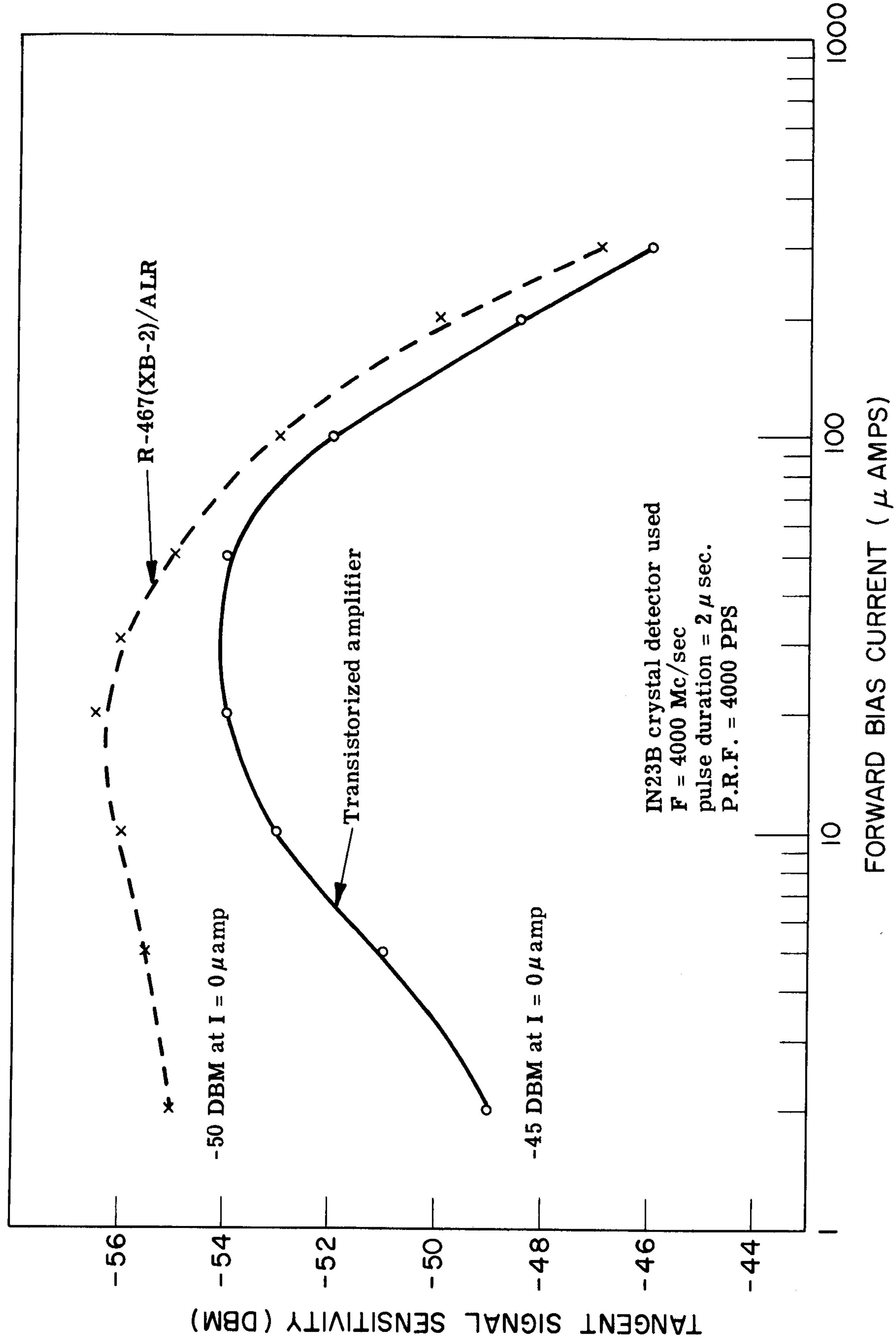

Figure 16 - Tangential signal sensitivity as a function of crystal bias current

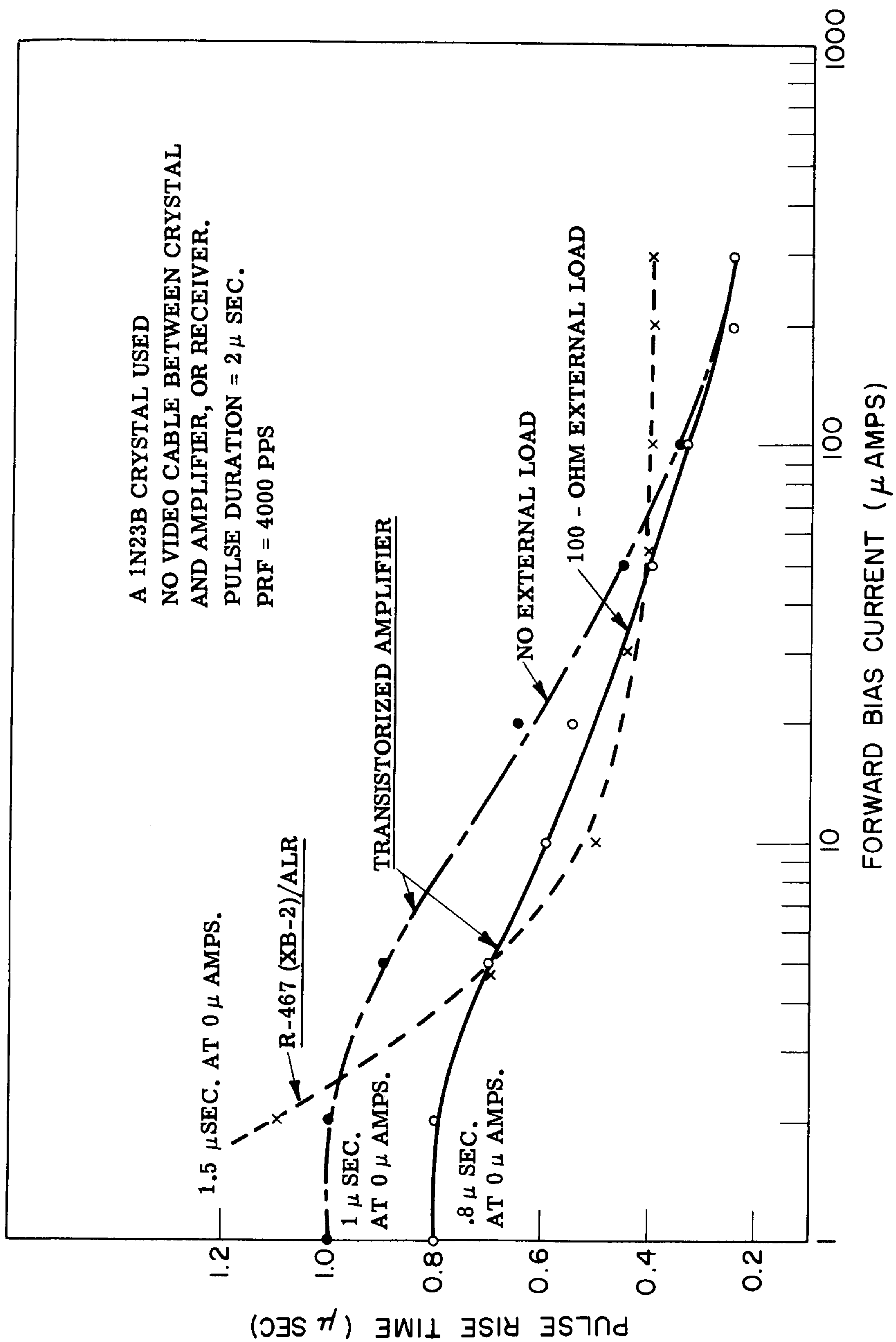

Figure 17 - Pulse rise time as a function of crystal bias current

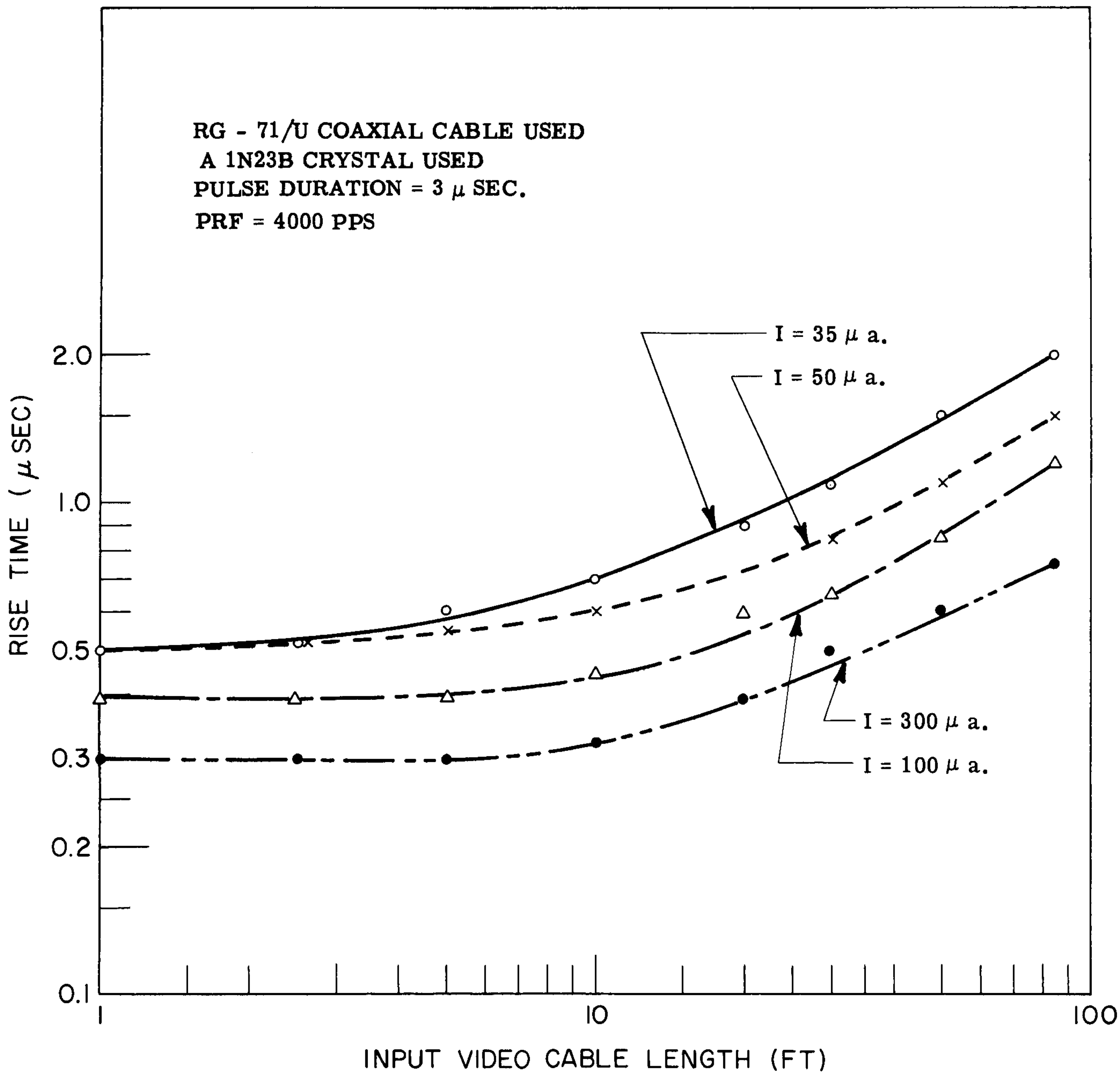

Figure 18 - Pulse rise time as a function of input video cable length between amplifier and IN23B crystal using various bias levels

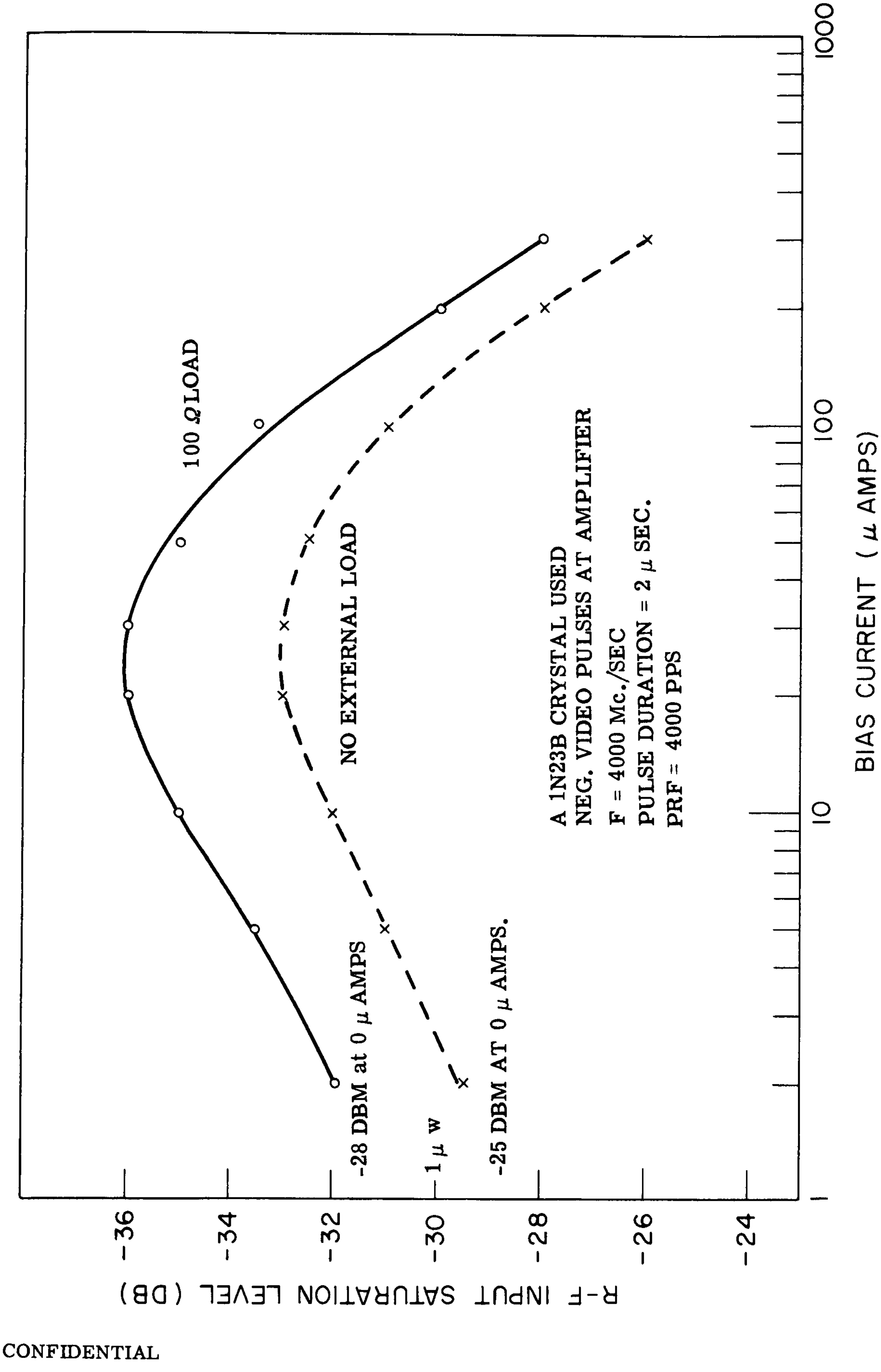

Figure 19 - Input saturation level versus crystal bias current

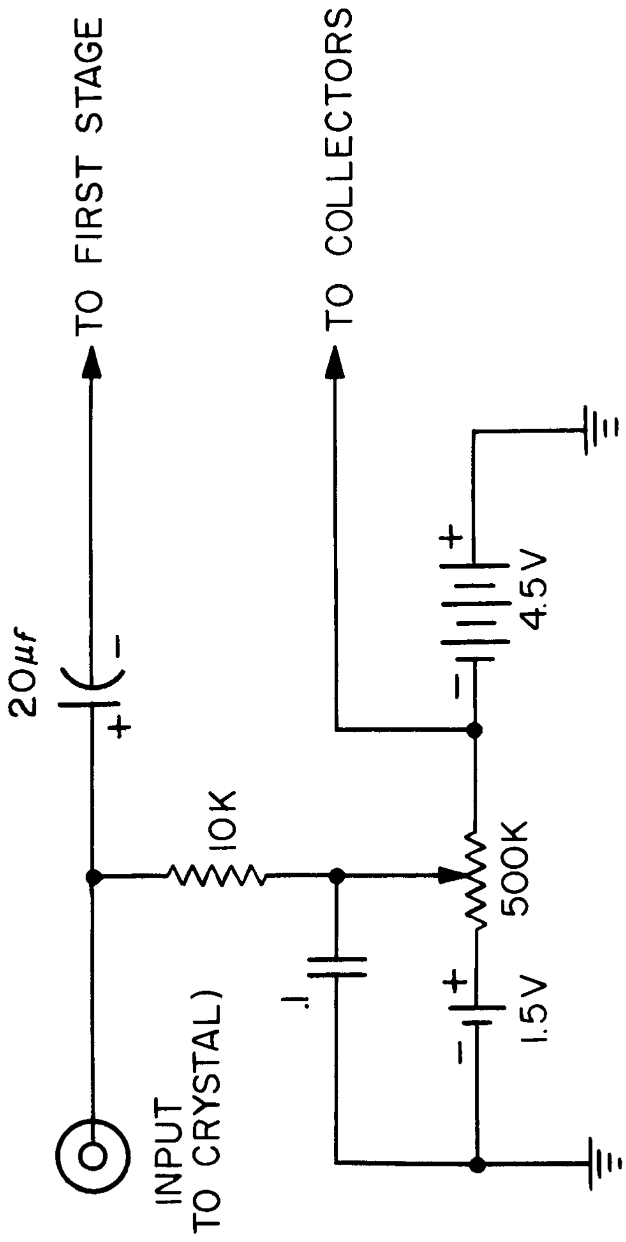

Figure 20 - Gain control circuit

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